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IOC/IASC/IHO Editorial Board for the International Bathymetric Chart of the Arctic Ocean

Report of Meeting: Dartmouth, Canada; June 24, 1999

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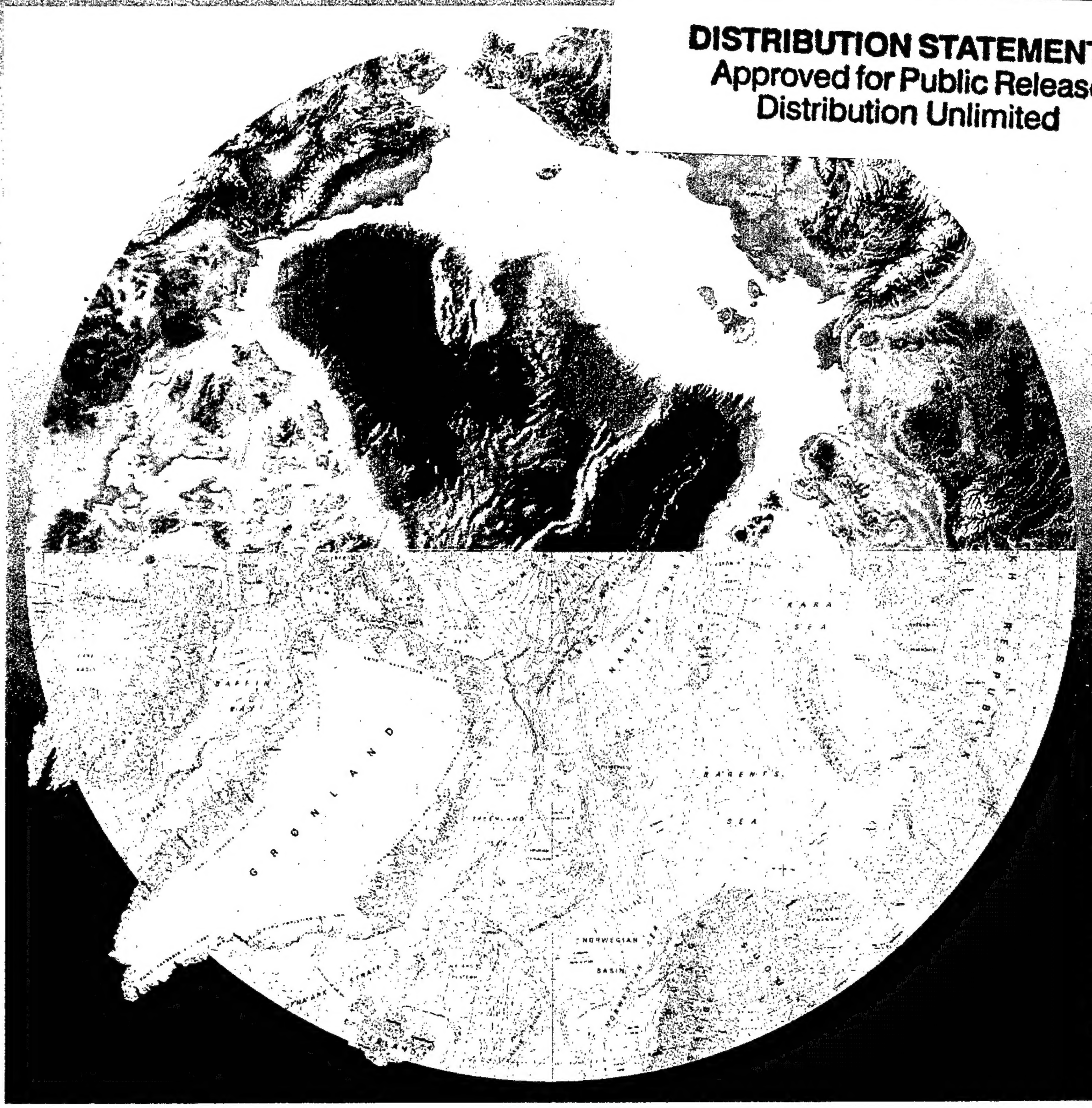

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	1999	Final Report

4. TITLE AND SUBTITLE
IOC/IASC/IHO Editorial Board for the International Bathymetric Chart of the Arctic Ocean (EB-IBCAO). Report of Meeting: Dartmouth, Canada; June 24, 1999.

5. FUNDING NUMBERS
N00014-99-1-1060

6. AUTHOR(S)
Multiple

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Geological Survey of Canada
Bedford Institute of Oceanography
Dartmouth NS, Canada

8. PERFORMING ORGANIZATION REPORT NUMBER
GSC Open File 3859, Nov 99

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research International Field Office
PSC 802 Box 39
FPO AE 09499-0039

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

This work relates to Department of the Navy Grant N00014-99-1-1060 issued by the Office of Naval Research International Field Office. The United States has a royalty free license throughout the world in all copyrightable material contained herein. Best available copy.

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12b. DISTRIBUTION CODE
A

12. ABSTRACT (Maximum 200 words)
This report summarizes a series of presentations that were delivered at the Bedford Institute of Oceanography on June 24, 1999, in a special session on Artic Bathymetry that took place during the Sixteenth annual Meeting of the GEBCO Sub-Committee on Digital Bathymetry (SCDB). The objectives were to outline the General Bathymetric Chart of the Oceans (GEBCO) and the nature and the scope of the initiative to develop the International Bathymetric Chart of the Arctic Ocean (IBCAO). In paper form the most recent version of GEBCO, 5th edition, was published by the Canadian hydrographic Service between 1975 and 1982. The first release of GEBCO in CD-ROM was in 1994; the third release is scheduled for the end of 2000. The IBCAO project was initiated for the primary purpose of constructing a modern digital database that contains all available bathymetric data north of 64N, for use by mapmakers, researchers and others whose work requires a detailed and accurate knowledge of the depth and shape of the Arctic seabed.

13. SUBJECT TERMS
General Bathymetric Chart of the Oceans (GEBCO); International Bathymetric Chart of the Arctic Ocean (IBCAO), Arctic Ocean; Navigation charts; Maps, Databases

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19, SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

IOC/IASC/IHO Editorial Board for the International Bathymetric Chart of the Arctic Ocean (EB-IBCAO)
Report of Meeting: Dartmouth, Canada; June 24, 1999

Summary of presentations in the Special Arctic Session held during the
Seventeenth Meeting of the GEBCO Sub-Committee for Digital Bathymetry (SCDB)
Dartmouth NS, Canada
June 24, 1999

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This work relates to Department of the Navy Grant N00014-99-1-1060 issued by Office of Naval Research International Field Office.

Geological Survey of Canada Open File 3859
November, 1999

***Cover figure:** A composite illustration that contrasts the characteristics of the new International Bathymetric Chart of the Arctic Ocean (upper half) and the existing Sheet 5.17 of the General Bathymetric Chart of the Oceans (lower half). The former is a working prototype constructed in February 1999 by Martin Jakobsson and Norman Cherkis from newly-available data sets and with modern techniques for data manipulation and digital cartography. The latter was constructed in 1979 by the Canadian Hydrographic Service from contemporary data sets and with manual cartographic techniques.*

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1. Introduction.

This report summarizes a series of presentations that were delivered at the Bedford Institute of Oceanography on June 24, 1999, in a special session on Arctic Bathymetry that took place during the Sixteenth annual Meeting of the GEBCO Sub-Committee on Digital Bathymetry (SCDB). Appendix A contains the session Agenda, while Appendix B lists the participants. The objectives of the session were:

- to outline to members of the SCDB, and through them to the GEBCO Guiding Committee, the nature and the scope of the initiative to develop the International Bathymetric Chart of the Arctic Ocean (IBCAO);

- to describe the results of recent work in constructing the IBCAO;

- to discuss procedures and timing for incorporating the IBCAO into GEBCO as a modern replacement for Sheet 5.17, the long-standing map of Arctic bathymetry;

- to inform members of the GEBCO ad hoc group on gridding of prospects for including the IBCAO grid in a new gridded model of global bathymetry.

Logistically, this special session was relatively straightforward to organize because several members of the Editorial Board for IBCAO were already participating in the GEBCO meeting in their capacities as members or associates of the SCDB.

By prior agreement with the Chairman and Secretary of the SCDB, the present report has been prepared as part of the body of documentation that is associated with the 1999 SCDB Meeting (IOC-IHO, in preparation), however it is being circulated separately on account of its specialized subject matter.

2. The General Bathymetric Chart of the Oceans (GEBCO).

Initiated at the turn of the century, the GEBCO is maintained under the joint auspices of the International Hydrographic Organization (IHO) and the Intergovernmental Oceanographic Commission (IOC). The project is managed by the Joint IHO/IOC Guiding Committee for GEBCO and its primary goal is to maintain and disseminate an authoritative bathymetric chart of the world's oceans.

In paper form, the most recent version of GEBCO, the Fifth Edition, was published by the Canadian Hydrographic Service between 1975 and 1982. It consisted of 16 Mercator sheets covering the world from 72°N to 72°S, on a scale of 1:10 million at the equator. Two polar stereographic sheets covered the polar regions to 64°N and 64°S respectively, on a scale of 1:6 million at 75° latitude. Each sheet depicted bathymetric contours at 200m, 500m and at 500m intervals thereafter, with some sheets also including contours at other intermediate depths.

Tracklines were included on the printed sheets to show the coverage of sounding data available when the contours were drawn.

In 1983, the GEBCO Guiding Committee set up its Sub-Committee on Digital Bathymetry (SCDB) to advise on how GEBCO could be taken into the digital era and be maintained in digital form. This resulted in a ten year project to create what is now called the GEBCO Digital Atlas (GDA). Using raster scanning techniques, all the bathymetric contours, coastlines and tracklines on the Fifth Edition printed sheets were digitized in the form of labelled vector streams expressed in geographic coordinates. The work was coordinated by the British Oceanographic Data Centre (BODC) and the First Release of the GDA was published by BODC on CD-ROM in 1994. A Second Release, including updated bathymetry for the southern Indian Ocean, the Weddell Sea and northeast Atlantic, was published in 1997.

The GDA now forms the base from which future printed editions of GEBCO will be generated. Without the scale and projection constraints of the printed charts, improved bathymetric contour compilations are being merged into the GDA at scales ranging from 1:10 million up to 1:500,000 or better, depending on the density of the sounding coverage. New data are 'stitched in' so as to maintain the seamless nature of the data set.

The Third Release of the GDA CD-ROM is scheduled for publication by BODC towards the end of 2000. In addition to updated contour vectors, the Third Release will also include a gridded version of the global bathymetry gridded at intervals of 2.5 minutes in latitude and longitude. Major updates envisaged for the Third Release include the whole of the Indian Ocean, the area around New Zealand, the Ross Sea, the northern part of the North Atlantic and, hopefully, the Arctic Ocean. The update for the Arctic Ocean is critically dependent on close collaboration with the IBCAO project.

3. The International Bathymetric Chart of the Arctic Ocean (IBCAO).

The IBCAO project was initiated for the primary purpose of constructing a modern digital data base that contains all available bathymetric data north of 64N, for use by mapmakers, researchers, and others whose work requires a detailed and accurate knowledge of the depth and shape of the Arctic seabed. Its conduct is overseen by an Editorial Board whose mandate has been endorsed by three international organizations: the International Hydrographic Organization (IHO), the Intergovernmental Oceanographic Commission (IOC), and the International Arctic Science Committee (IASC). Currently, the Editorial Board's membership consists of bathymetric specialists from eight countries with interests in Arctic mapping and research: Canada, Denmark, Germany, Iceland, Norway, Russia, Sweden, and the USA (see Appendix C).

Table I presents some of the project's historical highlights; additional information of an administrative and technical nature may be found in reports by Macnab and Grikurov (1997), and by Macnab and Nielsen (1998).

4. German bathymetric activities in the Arctic during the period 1998-1999.

Hans Werner SCHENKE, Alfred Wegener Institute, Bremerhaven

The RV "*Polarstern*", operated by the Alfred Wegener Institute in Bremerhaven, Germany, carried out three expeditions in Arctic waters from 27 June to 15 October 1998 (see Figure 1):

1. ARK XIV/1a (Bremerhaven-Tiksi) Joint cruise with the Russian Icebreaker "Arktika" to the central Arctic Ocean, 27 June to 28 July 1998: marine geophysics, multibeam bathymetry. Multibeam Hydrosweep survey was performed during the entire cruise, using D-GPS where available and GPS navigation. Multibeam and navigation data were checked and corrected where necessary. Data quality is reduced on account of ice. No systematic survey was performed. Data along the entire cruise track is available for bathymetric mapmaking, e.g. IBCAO.

2. ARK XIV/1b (Tiksi-Tromsö) Transdrift V Expedition to the Laptev Sea in cooperation with Russian scientists, 30 July to 26 August 1998: marine geology, partly multibeam, single beam during entire cruise. Narrow-beam echosounder observations were recorded during the cruise and stored in 1-second intervals in the "*Polarstern*" data bank. The data from this cruise was subsequently extracted from the archive and transferred to Martin Jakobsson and Norman Cherkis for use in portraying the bathymetry of the Siberian Shelf.

3. ARK XIV/2 (Tromsö-Bremerhaven) Nordic Seas, Fram Strait, Danmark Strait, 27 August to 10 October 1998: physical and chemical oceanography. Narrow-beam echosounder observations were recorded during the cruise and stored in 1-second intervals in the "*Polarstern*" system. The data sets have not been checked or analysed yet, however they are available from AWI upon request.

General information: During cruises with Hydrosweep multibeam surveys, the operation of the system is performed on a 24-hour basis by three watchkeepers. If possible the multibeam data and the navigation data are checked using the Hydrographic Data Cleaning System (HDCS) supplied by Universal Systems Limited (USL). Systematic surveys are generally performed in areas of special scientific interest, concentrated mainly in Fram Strait. It is planned to publish several 1:1,000,000 bathymetric charts covering all data west of 14°W between 78°N-80°N and 6°E and 2°W. Raw multibeam data from the Greenland shelf and in the Scoresby Sound have been transferred to the Royal Danish Administration of Navigation and Hydrography, for use in producing bathymetric charts.

Single beam observations are held in the "*Polarstern*" archive for many cruises since 1983. Most data sets (narrow beam soundings and navigation) have been neither checked nor cleaned. This tremendous amount of data could be available after extraction from the archives, followed by a check procedure using the analog recordings from"*Polarstern*". We estimate that one person-year would be necessary to carry out this work.

This year's *"Polarstern"* ARK XV expedition is divided into three legs:

1. ARK XV/1 (Bremerhaven-Tromsö) Physical oceanography and ROV-operation (Victor 6000) in the Fram Strait, 23 June to 19 July 1999. Single narrow beam sonar.

2. ARK XV/2 (Tromsö -Tromsö) Marine geophysics and geology, bathymetry in the northern Fram Strait and on the northern Greenland Shelf, 21 July to 8 September 1999. Multibeam sonar.

3. ARK XV/3 (Tromsö-Bremerhaven) Physical oceanography and sea ice studies, 10 September to 15 October 1999. Single narrow beam sonar.

5. Summary of RDANH activity in the IBCAO.

John WOODWARD, Royal Danish Administration of Navigation and Hydrography, Copenhagen

Since the last meeting of IBCAO in Copenhagen in October 1998, RDANH has been actively pursuing the identification and compilation of all relevant data sets within the Danish area of responsibility. Data sets have been acquired from the Danish Cadastre and Mapping agency (KMS - listed in Appendix D), the US and Royal Navy submarine programmes, and Polarstern cruises. The track plots of the data covered are shown in Figure 2. All data are in digital form with varying quality/traceablility, and have been released for general use.

Data set identification and compilation will continue in 1999 and in the future with the assembling of data: (a) from the Greenland and Denmark Geological Investigation (GEUS); (b) from the anticipated release of US Navy 1983-88 submarine data; (c) from future cruises of Polarstern and Poseidon; and (d) from prospective mapping operations in the Greenland EEZ during the SCICEX 2000 cruise.

6. Historic data collected by US Navy and Royal Navy submarines.

Norman Z. CHERKIS, Neptune Sciences Ltd., Reston VA

This report is a follow-on to reports presented at previous meetings of both GEBCO and the Editorial Board of the International Bathymetric Chart of the Arctic Ocean.

Beginning in 1957, US nuclear submarines began running under the ice-covered Arctic Ocean for strategic purposes. A number of years later, UK submarines conducted similar patrols for the same reasons. During a number of these patrols, bathymetric data were collected, and they were subsequently stored in classified databases in secure government installations.

In 1984, the Director of the Arctic Submarine Laboratory in San Diego, California, published a review of submarine navigation systems in the Arctic (Lyon, 1984). This showed tracks of numerous submarine patrols in the Arctic Ocean; however, it was unclear from the article whether bathymetric data had been collected along those tracks. In fact, soundings had been

collected, and subsequently digitized by personnel of the Naval Research Laboratory prior to consignment to the classified archives of the National Imagery and Mapping Agency (formerly the Defense Mapping Agency).

In 1997, Mr. George Newton, Chairman of the US Arctic Research Commission, initiated a series of negotiations that led to an agreement in principle by the US Navy's Deep Submergence Office (N-873) to release the sounding data collected along the Arctic tracks between 1957 and 1982. There were however caveats placed upon release of the data: no platform name, year, month or date could accompany the data. Further, any data that fell on continental shelves other than that of Canada were to be removed from the data sets. Fortunately, there were less than 100 soundings that actually met the latter criteria, and these were purged from the data set.

The Royal Navy had also collected soundings on several of their nuclear submarine cruises to the Arctic, and permission was obtained to release the British data sets with the same caveats as for the US data.

Of the 26 known cruises made in the Arctic Ocean between 1957 and 1982 (the first 25 years of nuclear submarine under-ice patrols), data from four were found to be in very poor condition with regard to either soundings or navigation, and these cruises were purged in their entirety. Data collected by the remaining 22 US and Royal Navy submarines were coarsely "blunder-checked" to locate gross cross-track errors. Several such errors were found and the erroneous data were analyzed and either corrected or deleted from the final data set. The remaining data, comprising over *240,000 positions and soundings,* were grouped as follows:

Group 1: Data collected between 1957 and 1962.
Group 2: Data collected between 1966 and 1972.
Group 3: Data collected between 1973 and 1982.

n.b.: No cruises were made and/or regional bathymetry collected in the Arctic Ocean in 1963, 1964 and 1965.

Figure 3 shows the tracklines along which bathymetric data were collected between 1957 and 1982.

These data have been placed on CD-ROM for inclusion in the public-domain bathymetric database of the international science community via the National Geophysical Data Center, National Oceanic and Atmospheric Administration, US Department of Commerce. A presentation ceremony and formal release of the data CD-ROM are scheduled for July 7, 1999 in Boulder, Colorado.

Following the release of the 1957-82 data, Mr. Robert Anderson, Associate Director of the US Arctic Submarine Laboratory, sought and obtained the release of bathymetry collected between 1983 and 1988. It is a significant data set, in that in these five years *alone,* there were 22 cruises to the Arctic by US nuclear submarines. However, a search of the records indicates that only ten

of these cruises have been converted to digital form to date. The remainder are awaiting digitization, but presently without high priority, since other areas of the World Ocean demand more immediate attention from the groups that do the digitizing. However, it is only a matter of time until the final data sets are digitized, cleaned, and released. Caveats placed upon this data release are as above, but with one other restriction: the data must be only that collected inside the "SCICEX" or "Gore" Box. This box lies outside of the EEZ's of all coastal states bordering upon the Arctic Ocean, except for the USA. Data collected within the US EEZ, therefore, will be released. The ten cruises mentioned herein have been cleaned and submitted through channels for final approval prior to dissemination. Altogether, this data set contains about 14,000 releasable soundings.

7. Contribution of the SCICEX Project to IBCAO.

Bernie COAKLEY, Tulane University, New Orleans LA

Research conducted from icebreakers in the Arctic Ocean has been limited by the demanding environment; isolation, extreme temperatures and drifting pack ice restrict access and make systematic surveys of the ocean floor impossible. The polar oceans drive world ocean circulation, are rich in plant and animal life, and shape the world's climate. Our understanding of the continents that ring the Arctic Ocean is restricted by how little we know about the history of this deep ocean basin. If we are to have truly global models for climate or plate tectonics, we must understand how the Arctic Ocean formed and how it influences climate variations at lower latitudes. Given the restrictions imposed by the drifting pack ice, a submarine is the only practical means to efficiently observe the Arctic Ocean.

The SCICEX program of unclassified Arctic science cruises aboard Sturgeon-class nuclear-powered submarines has, since 1993, provided the only regular, reliable access to the deep Arctic Ocean basin for science. These US Navy submarines operate efficiently in the Arctic, below the permanent floating pack ice, conducting the first systematic surveys of Arctic bathymetry and water composition. The first six cruises (Figure 4) have yielded new data on the structure of the ocean basin, and the distribution of heat and salinity and composition of the water. Peaceful use of these fast attack submarines has provided an extraordinary opportunity to explore the Arctic Ocean basin.

While the US Navy has provided an exceptional opportunity, the potential of these cruises was not fully exploited due to a lack of suitable instrumentation. To remedy this situation, the National Science Foundation funded development of a suite of active sonars which were used on SCICEX cruises in 1998 and 1999 and may be used for future cruises. These instruments were installed for SCICEX 98 on the USS Hawkbill and were just removed in June of this year, after the completion of SCICEX 99.

One of these sonars, a SeaMARC™ type sidescan swath bathymetric sonar, maps a strip of seafloor as much as 16 kilometers across, revealing the detailed bathymetry and surface sediment texture of the Arctic seabed for the first time. The other instrument, a high-resolution chirp sub-bottom profiler, penetrates as much as 100 meters into the seafloor to reveal the stratification of

the Arctic sediments. Approximately 40,000 track km of swath and sub-bottom profiler data were collected during SCICEX 98 and 99.

Geophysical data acquisition during SCICEX 99 focused on the Chukchi Plateau, Lomonosov Ridge and the ultra-slow spreading Gakkel Ridge (Figure 4). The Chukchi Plateau survey was designed to search for peri-glacial features on the seafloor. A number of these features were observed and identified. The Lomonosov Ridge survey was designed to map three segments of the Ridge which can be distinguished by their contrasting internal structure, and to collect site survey data for a proposed ODP drilling leg. The Gakkel Ridge survey was planned to complete coverage of the faster spreading section of the ridge, complementing the data acquired during the 1998 survey.

The geophysical program carried out from these submarines has focused on the Gakkel and Lomonosov Ridges and the Chukchi Borderland, but data was collected throughout the basin during the oceanographic investigations carried out during SCICEX. Processing of the swath data collected in 1998 and 1999 is underway at the Hawai'i Mapping Research Group in Honolulu. Much of this data will be shown at the Fall meeting of the American Geophysical Union in San Francisco.

Prior to SCICEX 99, the US Navy restricted the SCICEX program to an operational area defined by the exclusion of all non-US EEZs and a few shallow shelf areas. This year, for the first time, the USS Hawkbill collected data in the EEZ of Norway, along the Yermak plateau, operating in these waters at the invitation of the Norwegian government. While invitations from the other circum-Arctic nations, particularly Canada and Greenland, would substantially expand the scientific utility of future SCICEX cruises, no invitations have been received as yet.

SCICEX 99 will be followed by at least one more cruise, scheduled for the USS L. Mendel Rivers in the early Fall of 2000. Discussions are presently underway between the US National Science Foundation and the US submarine fleet on whether a program of SCICEX-like cruises might extend beyond 2000.

The data collected during SCICEX is the largest addition to the unclassified data base for the Arctic Ocean since the early seventies. Approximately 60,000 km of narrow beam bathymetry data, approximately 100,000 km of gravity anomaly data and 40,000 km of swath and sub-bottom profiler data have been collected during 211 days in the operational area. This data is being used to study some of the outstanding features in the basin, but it has a second use. The aggregate data set also builds the scientific infra-structure of the basin. The data set is one of the primary contributions to the data base being used for the new International Bathymetric Chart of the Arctic Ocean (IBCAO; endorsed by IASC, IHO and IOC) and to develop international proposals for future icebreaker cruises to sample the seafloor. This data set is also a resource for determining the outer limits of circum-Arctic continental shelves under the provisions of Article 76 of the Law of the Sea.

8. Arctic Ocean bathymetry: from GEBCO to SCICEX.

David MONAHAN, Canadian Hydrographic Service, Ottawa ON

The remoteness and harsh operating conditions of the Arctic Ocean meant that very little bathymetric data had been collected and made public by the 1970s. In 1979, what was to be considered the authoritative bathymetric portrayal of the Arctic for close to two decades, GEBCO 5.17, was produced by an international group (Canadian Hydrographic Service, 1979). The creation of this map was possible because by then a few profiles collected by US nuclear submarines had been released to supplement the ice island data and the few scattered spot soundings that were all the direct data available (Figure 5). Interpretation of this meagre data set was aided by the existence of a smattering of geophysical data and an understanding, developed in the better studied oceans to the south, of how the sea floor is formed. To say that this was a sparse data set would be a major understatement. Not only was there very little data, what there was had no cohesion, no pattern, no continuity. Clearly the map made from it was speculative, and the authors (of whom I am one) showed the tracks on the published map to warn users of its non-robust origins.

On an ocean-wide scale, there has been very little new bathymetry data made public since the publication of GEBCO 5.17. The few basin-wide bathymetry maps published were mostly recasts of 5.17 incorporating any new data that had become available, e.g. the 1985 NRL Arctic chart (Perry et al, 1985) was based upon the GEBCO chart, and it also incorporated sounding data from a number of other cruises that visited the Arctic after 1978 (Norman Z. Cherkis, personal communication, 1997). There has also been more detailed work in restricted areas, but these have not been compiled into a coherent whole.

In contrast, the SCICEX program of unclassified science cruises on US Navy fast attack submarines has continuously measured water depth along its tracks, collecting one of the largest bathymetric data sets for the Arctic Ocean. The first five cruises have resulted in about 80,000 km of new track data distributed throughout the deep Arctic Ocean (Figure 4). The data obtained during the SCICEX program over much of the Arctic basin will improve the mapped location and form of the individual features in the basin. Equally important, the SCICEX bathymetry data set can form an internally consistent framework to which other data can be fitted.

The detailed data collected during systematic submarine surveys fills in areas that were not sampled by drifting ice islands, icebreakers or other surveys. Densification of the bathymetric data set reveals the major ridges in the basin in greater detail, which focuses the fuzzy image presented previously. As an example of the amplification provided by the new data, Figure 6 shows the sea floor profile between Alpha Ridge and Lomonosov Ridge. The profile reconstructed from GEBCO 5.17 shows these two Ridges to be separated by an Abyssal Plain; in fact, the new SCICEX single beam sounding data shows that the seafloor in this area possesses rugged relief, opening the possibility of a closer linkage between these two features.

Further comparisons reveal similar improvements to our knowledge of the Arctic Ocean floor.

9. The new Russian Bathymetric Chart of the Arctic Ocean.

Gleb UDINTSEV, Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, Moscow

This 1:5 Million scale Chart (Head Department of Navigation and Oceanography et al, 1999) was compiled jointly by a group consisting of the Head Department of Navigation and Oceanography, Russian Federation Navy (GUNiO); the Research Institute for Geology and Mineral Resources of the World Ocean, Ministry of Natural Resources (VNIIO); and the Russian Academy of Sciences (RAS - formerly the Academy of Sciences of the USSR). Figure 7 reproduces a portion of the map, illustrating the level of detail in the vicinity of the North Pole.

The map is based essentially on data collected during a long-term program to investigate the floor of the Arctic Ocean, undertaken by GUNiO in cooperation with VNIIO and RAS. Depth measurements were made by echosounding from drifting ice stations, surface vessels, and submarines, and were accompanied by a complex of geological-geophysical observations. Positioning was accomplished mostly with astronomic and geodetic techniques. Plotting sheets were compiled using conventional cartographic methods supplemented with computer graphics. On the continental shelf to a depth of 200 m, isobaths were drawn at intervals of 50 and 100 m; in deeper waters, they were drawn at intervals of 200 m. Isobaths were developed taking into account the results of geomorphologic investigations into irregularities of the ocean floor, as described from geological and geophysical observations. The isobaths were digitized.

This bathymetric chart is included in the new Atlas of the World Ocean that is planned for publication by GUNiO in the near future. Separate copies of the map can be obtained from GUNiO. The product will interest oceanographers and geologists who are concerned with the structure of the Arctic Ocean Floor. It is detailed enough for drawing certain conclusions about the geomorphology and tectonics of the Arctic Ocean Floor, representing the real length, width and structural features of the Gakkel Mid-Oceanic Ridge, its correlation with Mendeleev Ridge, and with the continental margin of the Siberian platform. Complex structures of the Chukchi Borderland and other continental blocks of the Eastern Arctic, such as the Lomonosov and Mendeleev Ridges, are very well represented. The map is very important for further development of the ideas of Global Tectonics.

10. Merging data sets to produce a new bathymetric grid and chart.

Martin JAKOBSSON, Stockholm University, Stockholm
Norman Z. CHERKIS, Five Oceans Consultants, Alexandria VA

Introduction

A substantial amount of bathymetric data has been collected in the Arctic Ocean since the 1979 publication of GEBCO 5.17, which covers the area north of 64°N (Canadian Hydrographic Service, 1979). Using modern digital cartographic techniques, we have started the process of assembling all available single beam echo-sounding data and all newly-released contours in order

to create a new bathymetric grid and chart for the area north of 64°N.

The new bathymetric data offers the potential for substantially improving the view of the sea floor as shown in GEBCO 5.17, clearly revealing a more complex morphology of several major Arctic Ocean undersea features, for instance the Lomonosov Ridge. So far we have completed 50% of the area that is encompassed by GEBCO 5.17, as shown in the Cover Figure; the upper half of this Figure portrays bathymetry and topography in shaded relief as produced from our digital grid; the lower half is reproduced from the original GEBCO 5.17. The contrast between the two maps illustrates the impact of newly-available data, as well as the evolution of digital cartographic techniques.

Data sets and methods

In 1991, the Russian Hydrographic Office began an unclassified release of hydrographic charts vital to navigational safety along the Northeast Passage and adjacent regions. These charts contained enough sounding data to produce bathymetric maps of good quality. Figure 8 shows which of these charts were used in our compilation of the Siberian Shelf bathymetry. They were first contoured manually, then scanned and digitized for edge-matching with deep-water contour information extracted from a new Russian chart (Head Department of Navigation and Oceanography et al, 1999). For the area south of Bering Strait, contours were extracted from a chart published by the US Naval Research Laboratory (Perry et al, 1985). Contour information was supplemented with a mix of existing and newly-available observations that were collected by submarines of the United States and the United Kingdom (1958 –1988), the Swedish Research Vessel I/B Oden (1991 and 1996), the German research vessel PFS Polarstern (1995), SCICEX (1993-1998), and the Canadian Hydrographic Service. Also, bathymetric data sets were retrieved from the archives of National Geophysical Data Center (NGDC) in Boulder CO, USA (Figure 9).

All data were imported to Intergraph's GIS system MGE (Modular GIS Environment) where the projection parameters were set to Polar Stereographic with true scale at 75°N on the WGS-84 ellipsoid and datum. Observations were corrected for sound velocity using Carter's Tables or CTD profiles, and color-coded by depth value in order to facilitate a visual inspection of outliers, cross track errors and the fit between contours and sounding data. Suspicious soundings were removed, and where the contours showed major discrepancies with the bathymetric soundings, we adjusted the contours manually to fit the new bathymetric track line data.

All data sets were then converted to an xyz coordinate system for further processing and gridding using GMT public domain software (Smith and Wessel, 1990). The reason for adopting an xyz coordinate system was to create a Cartesian grid representing a Polar Stereographic projection with a true scale at 75°N on the WGS-84 ellipsoid and datum; a non-Cartesian grid over the Arctic region has been shown to portray high latitude bathymetry in a distorted way due to the close spacing of grid cells near the Pole (Macnab et al, 1998). In the latest version of GMT (3.3.1) the projection parameters mentioned above can be set by the user (Walter Smith, personal communication, 1999).

Prior to gridding, the data was preprocessed and combined in the following three steps:

1) all data was block-median filtered in GMT using a block cell size of 6x6 km;

2) the result from step 1 was combined with the original data where the older US Navy submarine tracks had been removed due to higher navigational errors;

3) the resulting data set after step 2 was block-median filtered over a block cell size of 2.5x2.5 km.

Gridding of the data at a grid cell size of 2.5x2.5 km was performed using the surface under tension algorithm available in the GMT software (Smith and Wessel, 1990), with the tension parameter set to 0.99. We found that the three steps of preprocessing the data yielded a reasonably good blending between the trackline and contour data. However, several tedious iteration steps were necessary during which we gridded the processed data and visualized the result with shaded relief in order to identify mismatches between contours and track lines. The contours were subsequently adjusted and the data re-gridded until we achieved a satisfactory result.

11. A summary of the SCICEX program.

George NEWTON, US Arctic Research Commission, Arlington VA

Early days and the establishment of a program

In 1989 and 1990, the US Navy acquiesced to requests from the civilian science community by agreeing to conduct specific experiments during classified ("ICEX") deployments under the Arctic pack ice by nuclear submarines. This led to discussions over the next three years concerning the potential benefits to both the Navy and the research community of dedicated science cruises under the ice, but the US Navy remained unreceptive to the concept until the end of the Cold War in1992. In early 1993, the Navy agreed to conduct a proof-of-concept cruise within a well-defined collection area; cruise planning was done by an ad hoc group from the Arctic Ocean research community during the Spring and Summer of 1993; later that year, USS PARGO spent 19 days under the ice, carrying five civilian investigators and collecting data over 4,800 nm (8,890 km) of track.

Following the PARGO mission, the Navy and the civilian science community assessed the results of the cruise, and concluded that mutual benefits had accrued, thus setting the stage for negotiations between four civilian science Agencies and three US Navy Commands to investigate prospects for a continuation of civilian involvement in future missions. Agreement was reached in 1994 for a series of annual cruises beginning in 1995 and ending in 1999; this program was christened SCICEX for Science Ice Exercise.

During the 1995-1997 missions aboard USS CAVALLA, ARCHERFISH, and POGY, water depth was measured with narrow-beam echo sounders, however for the 1998 and 1999 missions

aboard USS HAWKBILL, the vessel was equipped with a Seafloor Characterization And Mapping Pod (SCAMP) that was designed and constructed especially for the SCICEX program. SCAMP encapsulated a modified SeaMARC II swath mapping system for measuring bathymetry, and a chirp sonar for measuring sediment thickness. The performance of this new instrumentation exceeded all expectations.

Current status and future prospects

In October 1998, the naval and civilian communities held a Workshop to review overall results of the SCICEX program, and to consider whether a continuation of the program was warranted beyond 1999.

Overshadowing these discussions has been the fact that the SSN 637 Class submarines are being rapidly retired. As the Navy's most capable platforms for under-ice missions, vessels of this Class have been deployed on all SCICEX missions to date. However as a new opportunity, the US Navy recently offered to make the USS L. MENDEL RIVERS available for one additional SCICEX cruise in the year 2000.

Following the 1999 mission, with all cruises having accumulated a total of over 52,000 nm (96,300 km) of track in the data collection area after collectively spending 211 days under the ice, the US Navy broadened its offer by proposing negotiations aimed at deploying the USS L. MENDEL RIVERS as a dedicated science submarine until the vessel's projected mandatory retirement in the year 2008. If this proposition translates into reality, it could open many new ocean research horizons that have yet to be explored, however it seems clear that Arctic mapping is likely to remain a major beneficiary of the extended SCICEX program.

Prospects are very encouraging, therefore, for obtaining more and better bathymetric observations in the deep basins of the Arctic Ocean.

Acknowledgements.

This meeting was hosted by the Atlantic Division of the Geological Survey of Canada (Director Jacob Verhoef) and the Atlantic Region of the Canadian Hydrographic Service (Director Richard MacDougall). Staff of Fisheries and Oceans Canada and Natural Resources Canada assumed logistical responsibility for staging the event at the Bedford Institute of Oceanography; in particular, Ken Grant of the Canadian Hydrographic Service and Wayne Prime of the Geological Survey of Canada provided Internet access support to attendees during the meeting. The US Office of Naval Research International Field Office - Europe sponsored the attendance of several key participants. Richard MacDougall of the Canadian Hydrographic Service and Richard Pickrill of the Geological Survey of Canada reviewed the manuscript and offered valuable criticisms. Gary Grant of the Geological Survey of Canada constructed the report's front cover.

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Table I

The IBCAO Project: Milestones

October 1996

Scientific and Technical Workshop in Lomonosov-St. Petersburg, hosted by PMGE: *The Continental Shelf Beyond 200 Nautical Miles in the Arctic Ocean.* Recognition of the need to consolidate all available information

September 1997

Workshop in St.Petersburg, hosted by VNIIO and sponsored by IASC: *Arctic Bathymetry.* Review of available data sets and formation of a working group which later became the IOC/IASC/IHO Editorial Board for the International Bathymetric Chart of the Arctic Ocean (EB-IBCAO)

October 1998

First EB-IBCAO Meeting in Copenhagen, hosted by RDANH and sponsored in part by ONR. Discussion of procedures for building new data base, allocation of responsibilities, development of work plan

February 1999

Preliminary integration of major data sets, performed at Stockholm University with partial ONR sponsorship

Appendix A

Agenda: Special Arctic Session of the
GEBCO Sub-Committee for Digital Bathymetry.
Thursday June 24, 1999.

Co-Chairmen: Meirion JONES (BODC) and Ron MACNAB (GSC)

1. **Introducing the International Bathymetric Chart of the Arctic Ocean.**
   Ron MACNAB, Geological Survey of Canada, Dartmouth NS

2. **Recent data collected by German agencies.**
   Hans Werner SCHENKE, Alfred Wegener Institute, Bremerhaven

3. **Recent data collected by Swedish agencies.**
   Martin JAKOBSSON, Stockholm University, Stockholm

4. **Data in Greenland waters.**
   John WOODWARD, Royal Danish Administration of Navigation and Hydrography, Copenhagen

5. **Historic data collected by US submarines.**
   Norm CHERKIS, Neptune Sciences Ltd., Reston VA

6. **Recent data collected during 1993-99 cruises of the USN/NSF/ONR SCICEX program.**
   Bernie COAKLEY, Tulane University, New Orleans LA

7. **A comparison of GEBCO Sheet 5.17 and selected SCICEX profiles.**
   David MONAHAN, Canadian Hydrographic Service, Ottawa ON

8. **A new chart of the Arctic Ocean, developed by the Russian Navy.**
   Gleb UDINTSEV, Vernadsky Institute of Geochemistry, Moscow

9. **Merging data sets to produce a new bathymetric grid and chart.**
   Martin JAKOBSSON, Stockholm University, Stockholm

10. **Prospects for future mapping and research missions aboard US submarines.**
    George NEWTON, US Arctic Research Commission, Arlington VA

11. **Discussion.**

Appendix B

Participants: Special Arctic Session of the
GEBCO Sub-Committee for Digital Bathymetry

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Michael CARRON, USA

Norman Z. CHERKIS, USA

Bernard COAKLEY, USA

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Larry MAYER, Canada

David MONAHAN, Canada

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Arne NIELSEN, Denmark

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Desmond SCOTT, UK

Walter SMITH, USA

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Gleb UDINTSEV, Russia

Lois VARNADO, USA

Pauline WEATHERALL, UK

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Appendix C

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DK-1023 Copenhagen K
Denmark

Appendix D

Data contributions in the vicinity of Greenland, from Kort & Matrikelstyrelsen.

233 Andersen, Ole Bedsted: Surface-Ship Gravity Measurements in the Davis Strait, Western Greenland 1965. GIS, Ser. 3, Vol.XXXIX, 1973.

236 Sobczak, L.W., Stephens, L.E.: The Gravity Field of Northeastern Ellesmere Island, Part of Northern Greenland and Lincoln Sea, with map: No. 114 - Lincoln Sea. Gravity Map Series, Department of Energy, Mines and Resources, Earth Physics Branch, Ottawa 1974. Greenland land data replotted by Rene Forsberg, KMS, Dec. 1995.

240 Forsberg, R.: Gravity measurements in northern and north-eastern Greenland 1978-80. Recomputed (largely) final data, december 1985.

244 Geological Survey of Greenland: Marine gravity off East Greenland 1980. Survey by Western Geophysical, Processing by Rebbeck Hunter Ltd. 1984. Original data have been selected at approx. 2 km interval.

245 Geological Survey of Greenland: Marine gravity measurements off East Greenland 1981. Survey by "Seismic Profilers", processing by Rebbeck Hunter Ltd. feb 1984.

246 Geological Survey of Greenland: Marine gravity survey off East Greenland 1982. Data processed by Rebbeck Hunter Ltd., 1984.

247 Durham University: Marine gravity measurements off East Greenland 1973, 1974 and 1977. Data received from GGU, processed by Rebbeck Hunter, 1984.

248 Bundesgestalt fur Rohstoffe: Marine gravity measurements off East Greenland 1976 (Prof. Heinz, Hannover). Data received from GGU, processed by Rebbeck Hunter, 1984.

251 Marv A. Speece: Gravity Survey in the Godthaabfjord Area, 1988. Punched from received listings, fr jan 1990.

252 Geological Survey of Canada: Gravity measurements in the Davis Strait and Baffin Bay. Extract from GSC data base, april 1990. Replaces source no. 243. All data north of 76N deleted, and replaced by source 268, May 1996.

254 Rene Forsberg: KMS Gravity measurements in Greenland 1991-92. Ice measurements off Umanak 1991, Ata project 1991, South Greenland 1992.

256 KANUMAS gravity measurements off North-East Greenland 1991. Processed by Kort og Matrikelstyrelsen, June 1992.

259 GGU marine gravity measurements off West Greenland. Processed by KMS, Feb. 1993. Preliminary data - depths not screened!

263 Rene Forsberg: KMS gravity measurements in Greenland 1994 (Thule area)

264 Rene Forsberg: KMS gravity measurements in Greenland 1995 (Nares Strait, Station Nord and Ammassalik regions)

265 Marine gravity measurements, Nunaoil/KANUMAS 1994. Processed by KMS.

266 Marine gravity measurements in Fylla area, West Greenland. Nunaoil/KANUMAS 1994. Processed by KMS.

267 Marine gravity measurements, North-East Greenland. Nunaoil/KANUMAS 1995. Processed by KMS.

268 Gravity data from Jameson Land, surveyed by ARCO. Received from GGU 1996, reformatted by Gabriel Strykowski.

269 Marine data off SE Greenland, measured by commercial contractor for Danish Lithosphere Centre. Received from Trine Dahl Jensen, DLC, 1996.

270 Marine gravity data from central East Greenland fjords by R/V Polarstern. Received from Holger Mandler, Alfred Wegener Institute, 1992.

271 Marine gravity data from GGU survey by Thetis, 1995. Processed by KMS.

272 KMS gravity measurements on the Inland Ice at North Grip, Geikie and Saddle North, 1996 (ECOGIS project).

273 KMS Gravity measurements in North-East Greenland and Peary Land 1996-97.

323 Anon.: Sea gravity observed 1986 from Lance, received from Statens Kartverk, 1987.06.23. (mtcc4308).

328 Anon.: Land gravity, Svalbard, measured by Statens Kartverk 1985-86, received from Statens Kartverk Apr. 1988.

329 Anon.: Sea-gravity, CNEXO, Barents Sea, Norwegian Sea and North Sea, received from Statens Kartverk Jun. 1988.

335 Western Geophysical Union-data, received by CCT through DGU 1988. Gravity values created from GRS67 free air anomalies .

336 Gravity data from Iceland, received by rf Jan 94. Described in report "Gravity data and a gravity map of Iceland" (Thorbergsson et. al., Orkustofnun, Reykjavik, May 1993).

500 Andersen, Ole Bedsted: Surface-Ship Gravity Measurements in the North Atlantic Ocean 1965 and 1968. GIS, Ser. 3, Vol. XLI, 1975.

527 Anon.: Sea Scan Phase 1, USS Archerfish, Portsmouth, England to Hammerfest, Norway. Navoceano, 1960.

530 Anon.: Gravity data from Vema cruise 23. Lamont Doherty Geological Observatory, 1966.

535 Anon.: Meteor Ship Gravity Data Cruise 14, North Atlantic and North Sea. DHI, 1968.

536 Anon.: Meteor Ship Gravity Data Cruise 20, North Atlantic and North Sea. DHI, 1970.

707 Anon.: Paul Goffeny Cruise, BGI, SHOM, W.Ye., DMA source code: 6087.

713 Boulanger, Y.D.: C.M.A.N., Cruise 15 -- R/V Academic Kourchatov. USSR Acad.Sc., IEP, 1973. DMA source code: 6094.

714 Anon.: - see 711, ID 70005711. DMA source code: 5367.

739 Anon.: Gravity Data, Cruise 4 -- R/V Meteor, DHI (BGI), 1966. DMA source code: 6084.

740 Anon.: Meteor Ship Gravity data, North Atlantic Ocean. DHI, 1966. DMA source code: 3822.

744 Anon.: USNS Shoup gravity data, North Atlantic Ocean, 10032. NAVOCEANO, 1967. DMA source code: 2961.

774 Anon.: French Atlantic Ocean and Mediterranean Gravity surveys. C.N.E.O., 1972. DMA source code: 5308.

780 Anon.: Gravity survey in the Northwest Atlantic. BGI, W.Ye DMA source code: 6319.

786 Mould, A.S., A. Dobinson, R.A. Floyd and M.C. Tully: MGUP 74/04 -- M/V Briarthon Shetland Islands Survey. IGS, 1974. DMA source code: 6107.

787 Tully, M.C.: MGUP 71/05 -- M/V Researcher, Regional Geophysical Surveys offshore N.W. Scotland. IGS, 1971. DMA source code: 6116.

794 Anon.: Meteor ship gravity data cruise 28, North Atlantic and North Sea. DHI, 1972. DMA source code: 4369.

803 Anon.: Komet ship gravity data, North Atlantic Ocean. DHI, 1971. DMA source code: 4370.

869 Marine gravity data - R/V Conrad-cruise 21, leg 14, Norwegian Sea. NOAA, Lamont Doherty Geological Observatory, 1978. DMA source code: 7291.

870 Marine gravity data - R/V Conrad-cruise 21, leg 15, Atlantic Ocean. NOAA, Lamont Doherty Geological Observatory, 1978. DMA source code: 7292.

924 Marine gravity data, R/V Starella, cruise 1/79 part B, North Atlantic Ocean. NOAA, Institute of Oceanographic Sciences, 1979. DMA source code: 7435.

925 Marine gravity data, R/V Starella, cruise 1/79 part B, North Atlantic Ocean. NOAA, Institute of Oceanographic Sciences, 1979. DMA source code: 7436.

931 Marine gravity data, R/V Shackleton, cruise 8/77, North Atlantic. NOAA, Institute of Oceanographic Sciences, 1977. DMA source code: 7485.

935 Marine gravity measurements off East Greenland 1973, 1974 and 1977.R.R.S. Shackelton, UK. Geodaetisk Institut, Durham University, 1977.DMA source code: 7733.

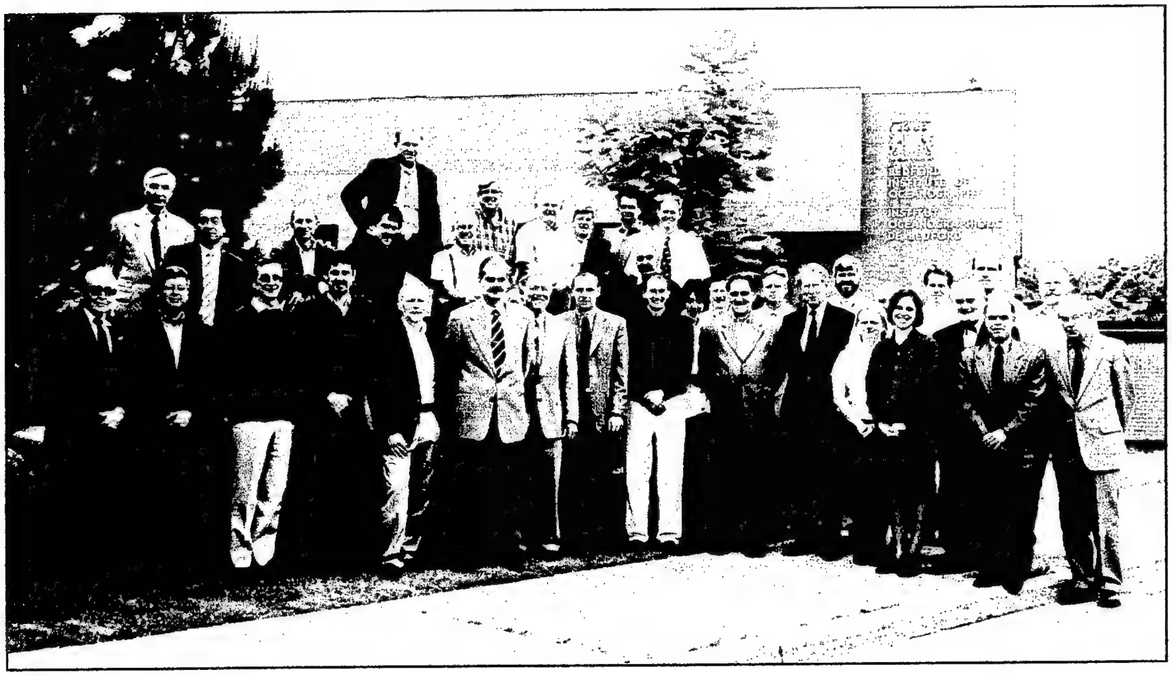
Appendix E

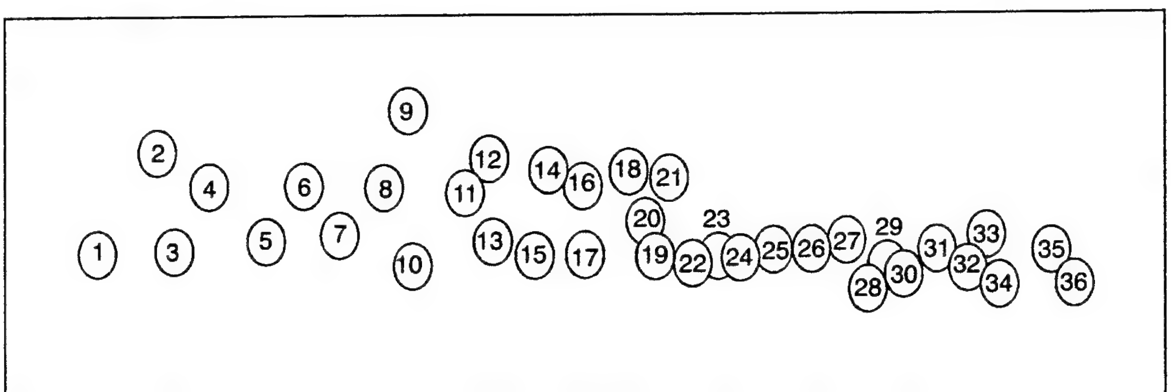
Abbreviations and Acronyms

AWI	Alfred Wegener Institute
BODC	British Oceanographic Data Centre
CD-ROM	Compact Disk Read-Only Memory
CTD	Conductivity-Temperature-Depth
D-GPS	Differential Global Positioning System
EB-IBCAO	Editorial Board for the International Bathymetric Chart of the Arctic Ocean
EEZ	Exclusive Economic zone
GDA	GEBCO Digital Atlas
GEBCO	General Bathymetric Chart of the Oceans
GEUS	Geological Survey of Denmark and Greenland
GIS	Geographical Information System
GMT	Generic Mapping Tool
GPS	Global Positioning System
GUNiO	Head Department of Navigation and Oceanography, Russian Federation Navy
HDCS	Hydrographic Data Cleaning System
IASC	International Arctic Science Committee
IBCAO	International Bathymetric Chart of the Arctic Ocean
ICEX	Ice Exercise
IHO	International Hydrographic Organization
IOC	Intergovernmental Oceanographic Commission
KMS	Kort & Matrikelstyrelsen (Danish Cadastre and Mapping Agency)
NGDC	(US) National Geophysical Data Centre
NRL	(US) Naval Research Laboratory
ODP	Ocean Drilling Program
PMGE	Polar Marine Geosurvey Expedition
RAS	Russian Academy of Sciences
RDANH	Royal Danish Administration of Navigation and Hydrography
ROV	Remotely-Operated Vehicle
SCAMP	Seafloor Characterization And Mapping Pod
SCDB	Sub-Committee on Digital Bathymetry
SCICEX	Science Ice Exercise
USL	Universal Systems Limited
USS	United States Ship
VNIIO	All-Russia Research Institute for Geology and Mineral Resources of the World Ocean

GEBCO 1999 Meetings

June 22-30, 1999
Bedford Institute of Oceanography, Dartmouth NS, Canada





1 Robert FISHER
2 Gleb UDINTSEV
3 Luis G. CAMPOS
4 YASHIMA Kunio
5 Patrick SOUQUIERE
6 Michael CARRON
7 John WOODWARD
8 Meirion T. JONES
9 Michel HUET
10 William RANKIN
11 Norman Z. CHERKIS
12 John K. HALL
13 Alexis HADJIANTONIOU
14 Michael LOUGHRIDGE
15 Hans Werner SCHENKE
16 David MONAHAN
17 Arne NIELSEN
18 Bernard COAKLEY
19 Andrew GOODWILLIE
20 Peter HUNTER
21 Tony PHARAOH
22 Pauline WEATHERALL
23 Larry MAYER
24 Brian HARPER
25 Marcus ALLSUP
26 Anthony LAUGHTON
27 Walter SMITH
28 Lois VARNADO
29 Richard A. MARTINO
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31 Martin JAKOBSSON
32 Neil GUY
33 Trent PALMER
34 Marco Antonio OLIVEIRA
35 Ron MACNAB
36 Desmond SCOTT

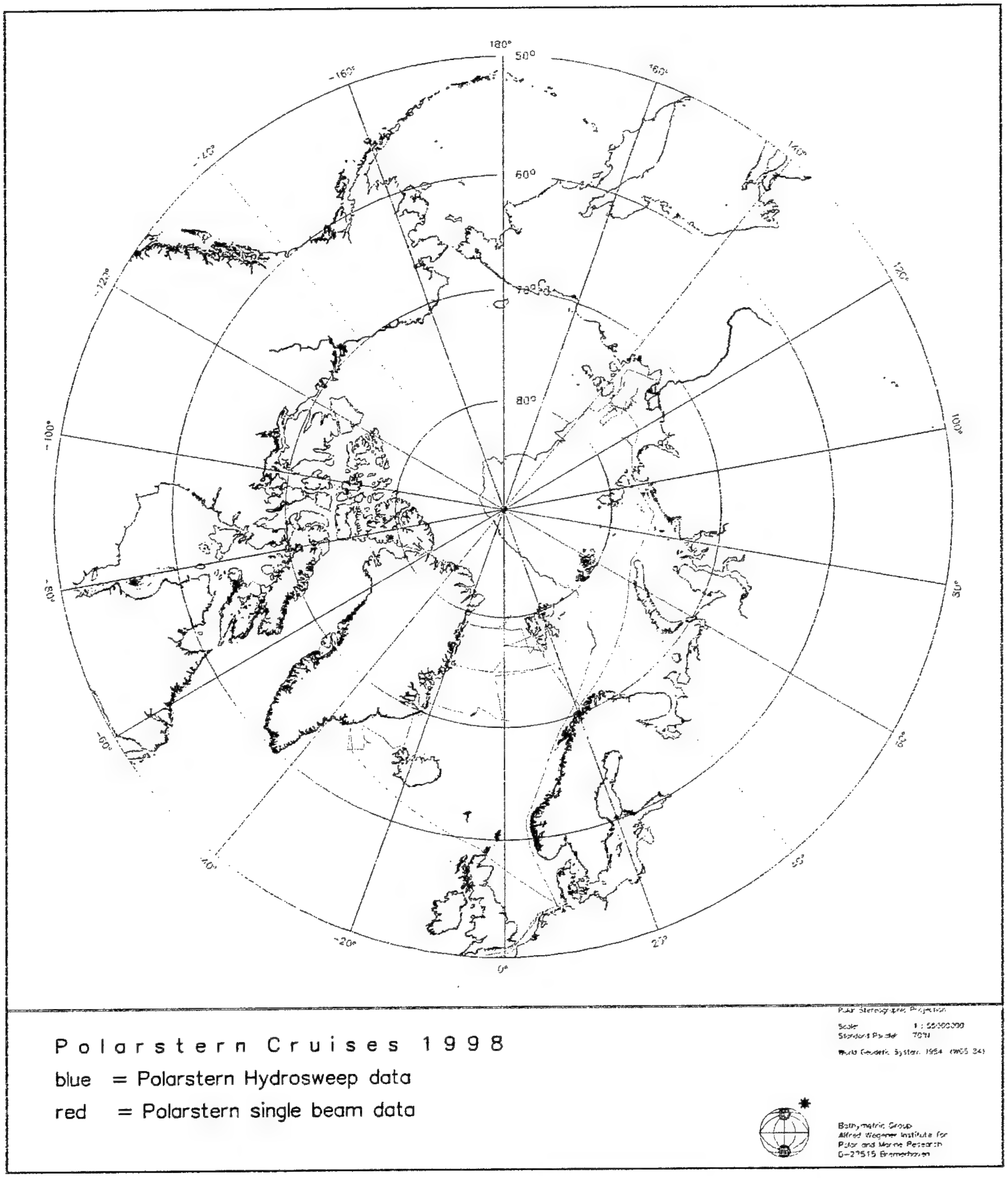

Figure 1. RV Polarstern cruises in 1998 (Schenke).

Figure 2. Locations of bathymetric observations in the vicinity of Greenland, compiled by RDANH (Woodward).

Figure 3. Tracklines along which bathymetric data were collected by US and UK submarines between 1957 and 1982 (Cherkis).

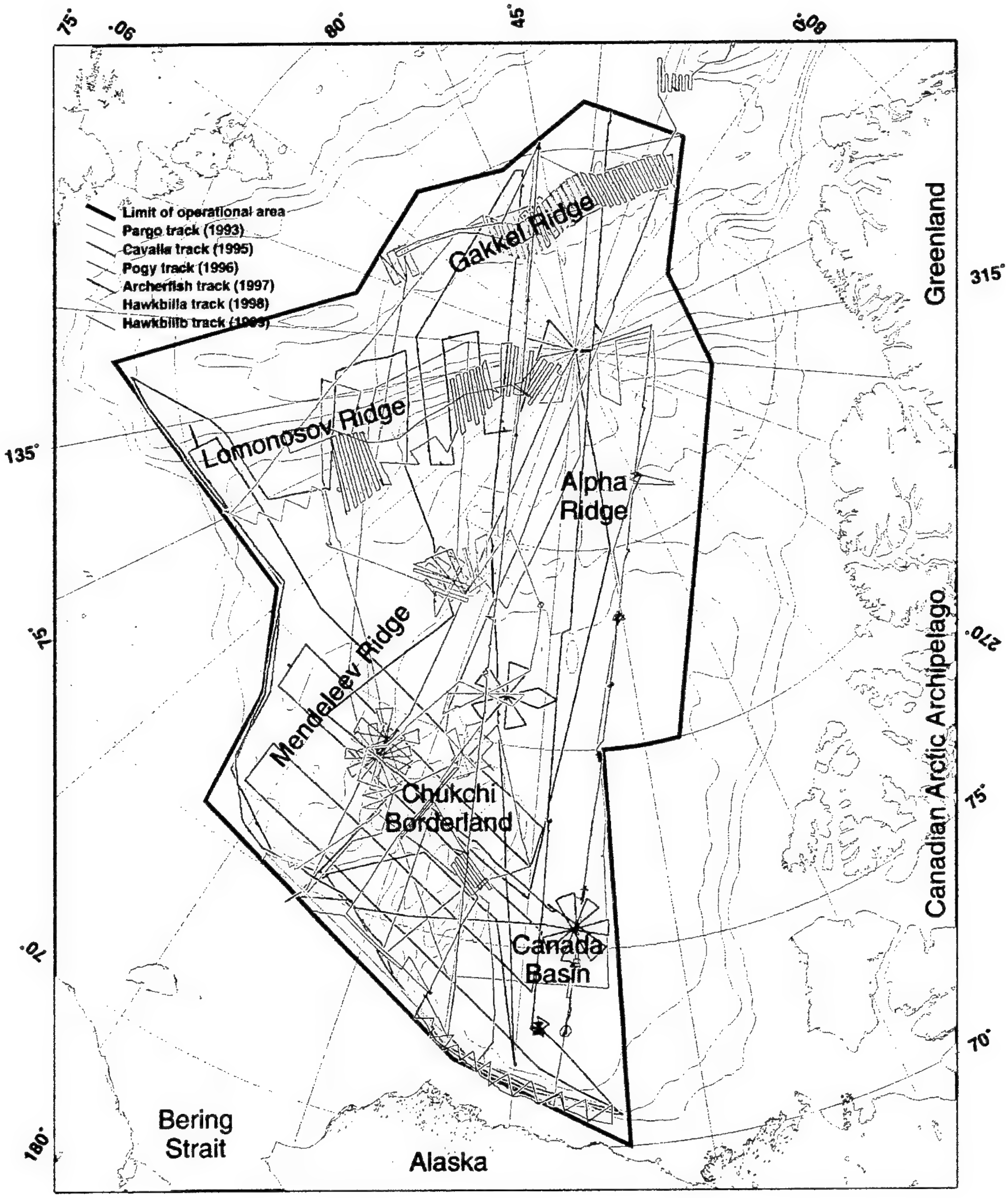

Figure 4. Tracklines of SCICEX cruises from 1993 to 1999 (Coakley).

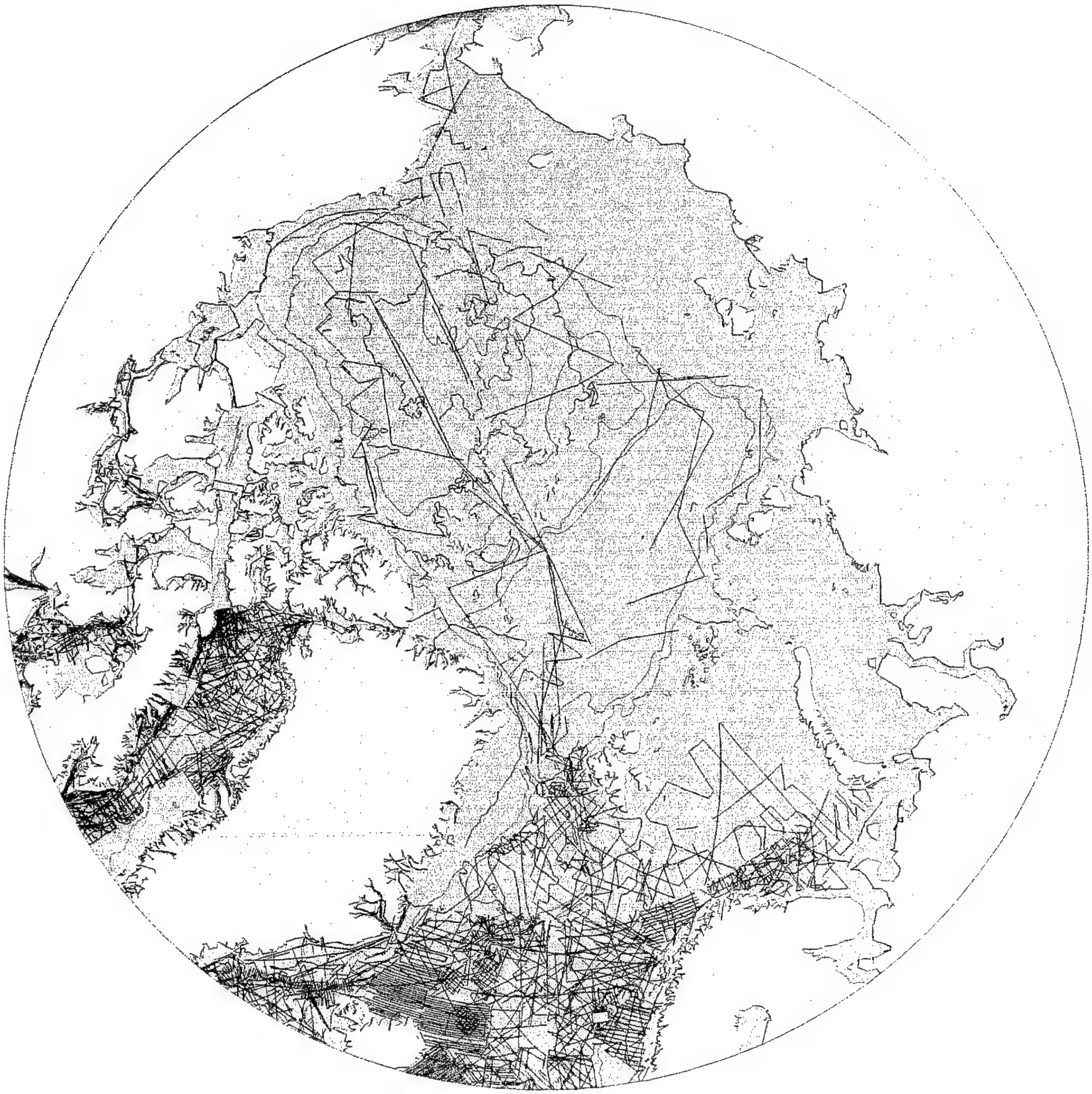

Figure 5. Tracks of single beam or spot sounding data that existed at the time of construction of GEBCO Sheet 5.17 (extracted from the GEBCO Digital Atlas). Not all the soundings shown south of 72 °N were used in the preparation of this particular Sheet.

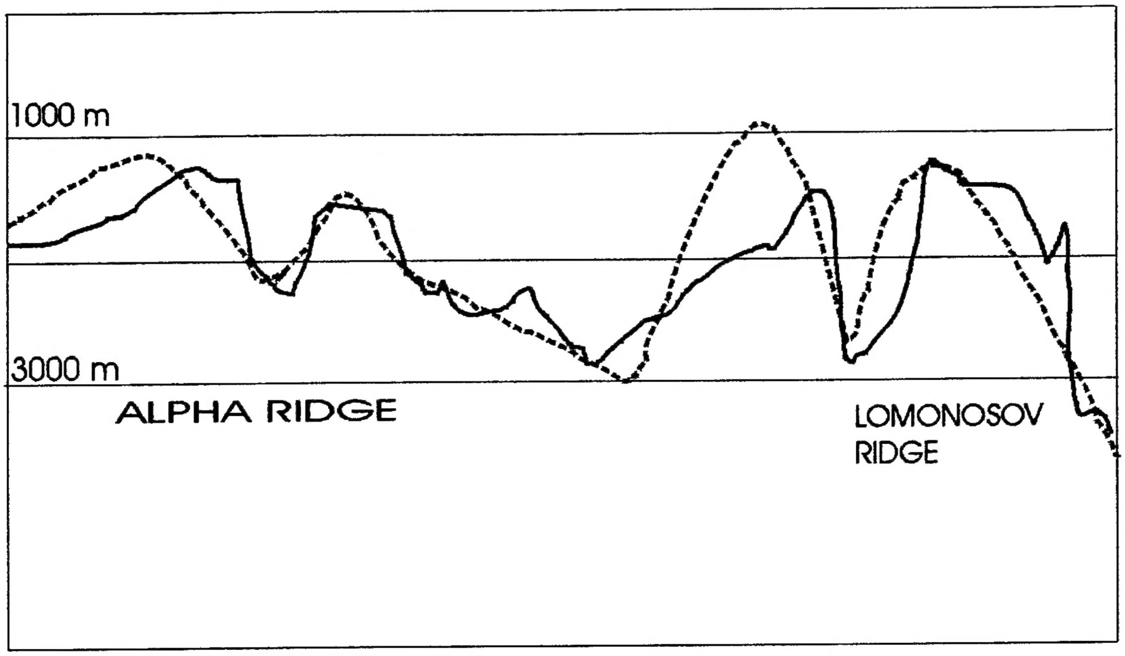

Figure 6. Profiles across the floor of the Arctic Ocean. The light broken line is reconstructed from GEBCO 5.17. The solid dark line is an echo-sounder trace from the SCICEX program (Monahan).

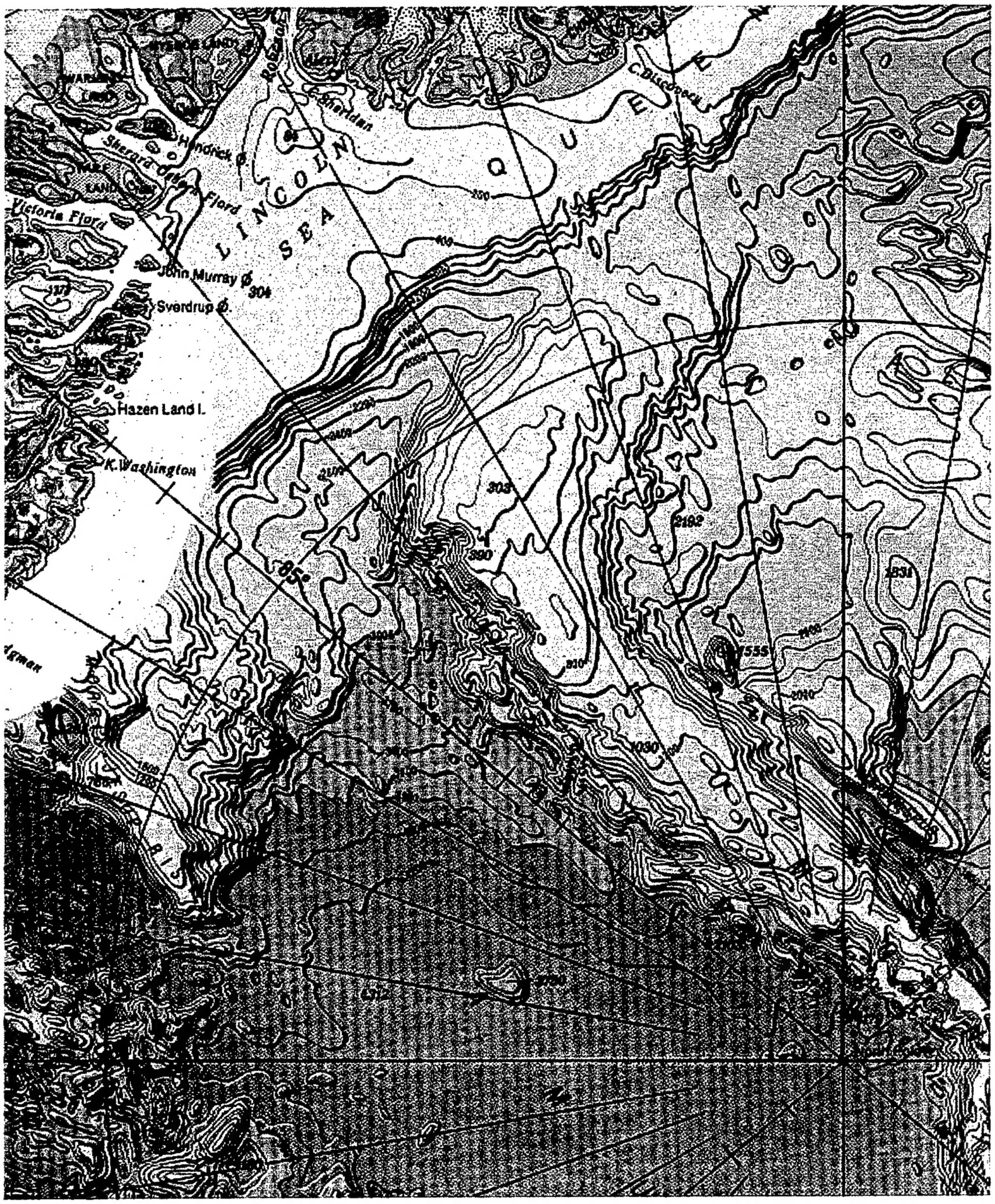

Figure 7. A portion of the new GUNiO/VNIIO/RAS map of Bottom Relief of the Arctic Ocean, showing detail in the region between the North Pole and the Lincoln Sea (Udintsev).

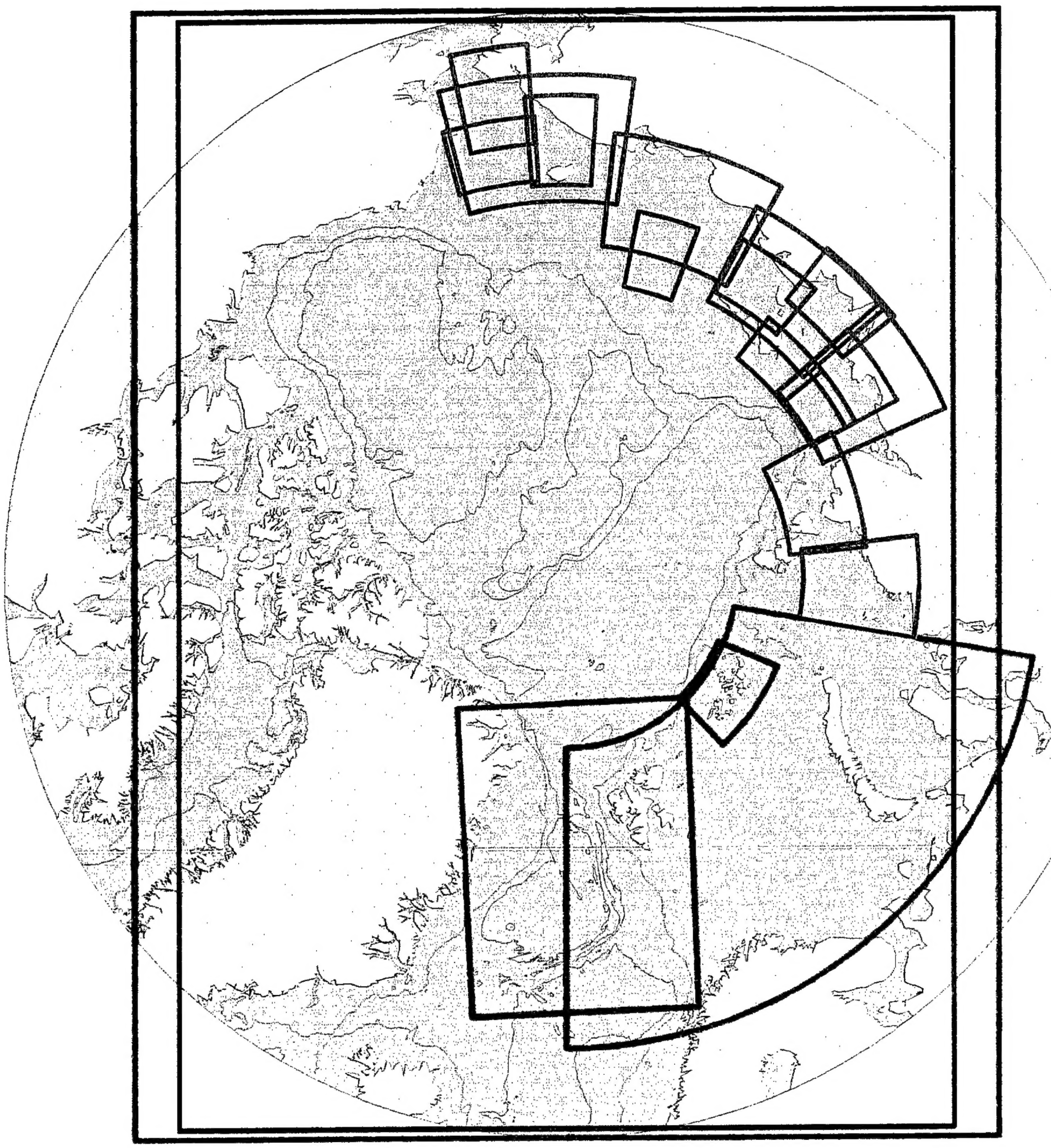

Figure 8. Areas where information was extracted selectively from navigational charts and published compilations for use in preparing the new Arctic map. Red outlines: navigation charts published by the Russian Federation Navy. Green outlines: compilation maps developed by the US Naval Research Laboratory, in collaboration with international partners. Purple outline: compilation map created by naval and civilian agencies of the Russian Federation (Cherkis).

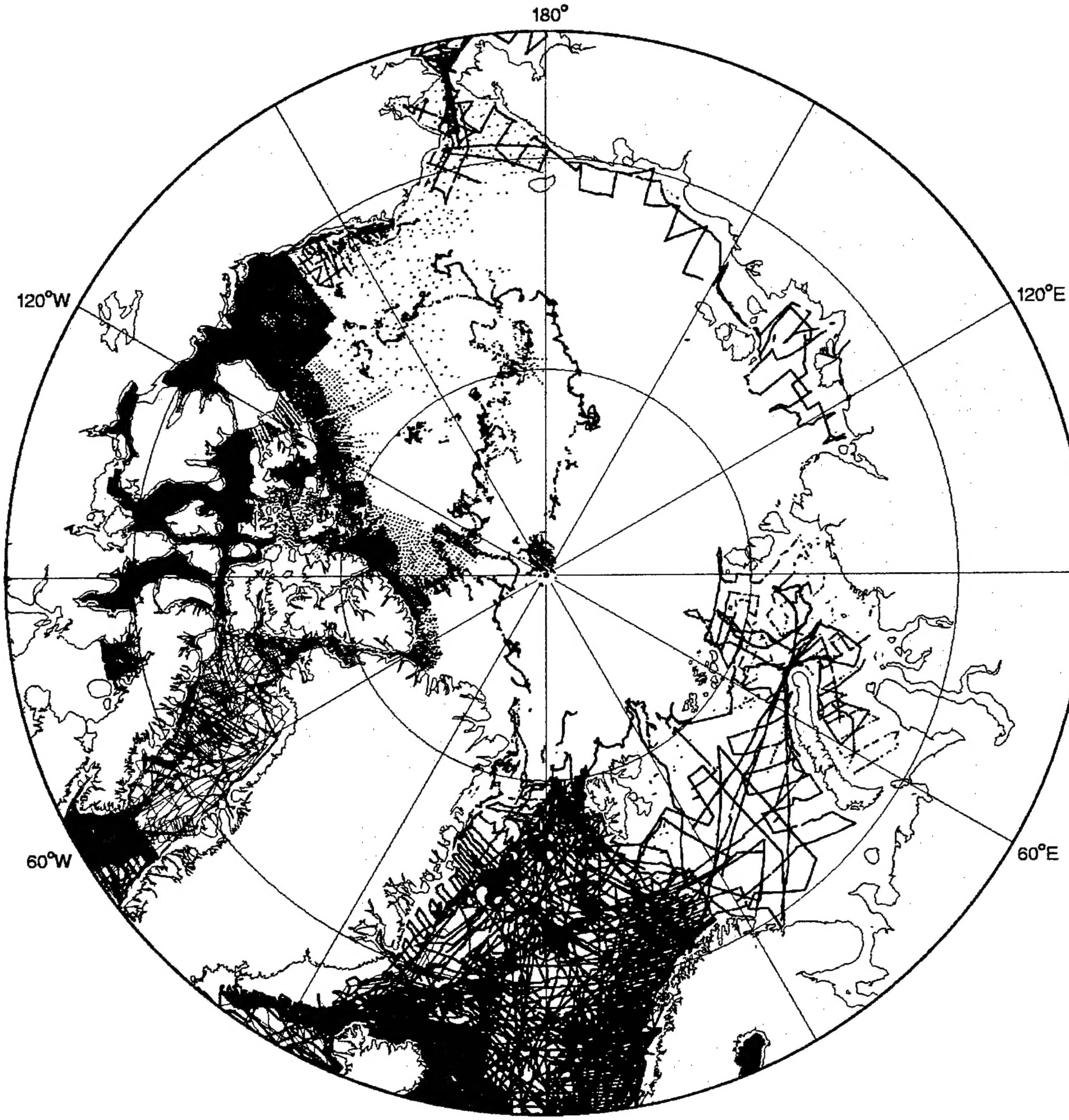

Figure 9. Bathymetric data sets retrieved from the digital archives of the US National Geophysical Data Center (NGDC) and of the Geological Survey of Canada (GSC).